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EXHAUST EMISSIONS FROM A MERCEDES-BENZ DIESEL SEDAN

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A Mercedes Diesel sedan was tested as part of the development of an official Federal Test Procedure for diesel-powered light duty vehicles. Results were also used in technology assessment efforts. The car was a Mercedes-Benz, 220 Diesel, four-door sedan, with a 134 CID four-cylinder Diesel engine developing 65 SAE horsepower. Power is transmitted to the rear wheels through an automatic transmission. The car was tested at a simulated inertia weight of 3,500 lbs. A total of 18 cold start tests, using the 1975 Federal test procedure, are reported. In addition, several tests were run with the car running at a steady state to investigate the effects of changing sampling locations and constant volume sampler flow rates. The paper discusses: apparatus used in tests; location of sample point; hot FID instruments; and particulate emissions. The results and conclusions are discussed in detail.

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APTD-1381

Final Report: Exhaust Emissions from a Mercedes-Benz Diesel Sedan

July 1972

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Background

A Mercedes Diesel sedan, obtained through the courtesy of Mercedes-Benz of North America, was tested at the Ann Arbor Motor Vehicle Emissions Laboratory during the period of December 1971 through May 1972.

The original objectives of these tests were to develop a procedure to accurately measure mass emissions from a Diesel-powered candidate vehicle in the Federal Clean Car Incentive Program, and to verify earlier published mass emissions data on another Mercedes 220 Diesel. Later these tests became important in the development of an official Federal Test Procedure for Diesel-powered Light Duty Vehicles, and the data became of interest in technology assessment efforts underway in the Division of Emission Control Technology.

Vehicle Description

The car was a Mercedes-Benz 220 Diesel four-door sedan, with a 134 CID four-cylinder Diesel engine developing 65 SAE horsepower. Power is transmitted to the rear wheels through an automatic transmission. The car was tested at a simulated inertia weight of 3,500 pounds. The first test was at an odometer reading of 2060 miles and the last at 4145 miles.

Test Program

1. Gaseous Emissions.

A total of 18 cold start 1975 FTP tests (3-bag) will be reported herein. In addition to these, several tests were run with the car running at a steady state to investigate the effects of changing sampling locations and Constant Volume Sampler (CVS) flow rates.

a. Apparatus

Instrumentation was as specified in the Federal Register, with exceptions as required by the characteristics of the Diesel car. Normal CVS bag samples were analyzed for unburned hydrocarbons (HC) with a Flame Ionization Detector (FID), for CO and CO_2 with Non-dispersive Infrared (NDIR) instruments, and for nitrogen oxides (NOx) with a Chemiluminescence (CL) analyzer. Three different CO analyzers were used, though not all on the same tests: a standard cell-length instrument with a range of about 0-2500 ppm, a similar instrument with EPA modifications having a range of 0-250 ppm, and a long path instrument with a range of 0-200 ppm.

Recognizing the problem of Diesel exhaust heavy hydrocarbon condensation on CVS ducts, sample lines and sample bags, it had been planned from the outset of the program to use a heated FID and a heated sample line for continuous HC analysis, with integration of the FID output signal giving average HC concentration over the appropriate test interval. Nominal FID and sample line operating temperature was 375°F. Strip charts from all tests were hand integrated by the writer using a planimeter. On a few tests an electronic counter was used as the integrator and gave good agreement on mass emissions (within 3%) with the hand integrations. Unfortunately the counter proved to be unreliable and could not be used on the remaining tests.

b. Sample Point

The location of the sample point was determined after considering these factors: HC concentrations in the raw exhaust can vary widely depending on engine operating mode, and "spikes" during transients are difficult to integrate. Calculation of mass emissions from the raw concentrations requires knowledge of engine exhaust flow rates and is therefore much more difficult than if a CVS is used. Thus, it was decided to sample from the dilute exhaust/air mixture.

On the first series of tests the sample was taken at the same point as the CVS bag, for the sake of expediency. It soon bec ame apparent that this was not a good sample point to use. The first reason is that the partial vacuum at that point, just upstream of the CVS Roots blower, is large enough to reduce sample flow to the FID, thereby reducing response. Secondly, there are several feet of relatively cold ducting and heat exchanger upstream of this point where the unburned heavy hydrocarbons can condense and be lost to analysis.

In general, diesel exhaust should be mixed with dilution air as close as practical to the vehicle tailpipe to minimize HC condensation. Also, the sample for the hot FID should be taken immediately after thorough mixing has occurred to ensure that a homogeneous exhaust/air mixture is sampled and to minimize further HC condensation.

Thus, after the first three tests a different CVS unit was employed, one in which the exhaust/dilution air mixing chamber was only about four feet downstream of the vehicle exhaust pipe. The pitot-type sample probe was placed in the center of the outlet duct, just inches downstream of the mixing chamber, and the sample transported to the hot FID through a heated sample line.

This set up had the effect of reducing response time of the FID to a change in engine operation from twenty seconds to four seconds. Traversing the duct with the probe revealed no appreciable stratification of the mixture.

Beginning with the fifth test (number 18-166), the pitot probe was replaced with a rake-type probe. Four equally spaced holes were drilled into a quarter-inch stainless steel tube in which one end was crimped and brazed closed. This probe extended diametrically across the duct with the holes facing upstream.

c. Hot FID Instruments

A Beckman Model 402 hot FID was used on the first twelve tests and on test No. 15 (18-284), in parallel with the Scott Model 215 hot FID used on the last six tests. Each of these units had a heated sample line as an integral part of ths system. Operating temperature was 375°F in both sample line and detector.

2. Particulate Emissions

The vehicle was taken to Dow Chemical, Midland, Michigan, for determination of particulate emissions by the Dow procedure, which includes the cold soak and driving schedule from the 1975 Federal Test Procedure. All the vehicle exhaust is collected and diluted with air. The samples are then taken from the dilute exhaust stream through isokinetic probes and collected on filters. From the mass of particulates collected on the filters the mass emissions, in grams per mile, are calculated.

Results and Discussion

1. Gaseous emissions as determined by the 1975 FTP are presented in Table I in grams per mile (gpm).

a. Hydrocarbons

There are two columns of HC data: the normal CVS bag results (column headed "HC Cold Bag"), and the results of integrating the continuous hot FID analysis (column headed "HC Hot FID"). All of the latter data is from the hand integrations of the strip charts. On the first six tests the HC data follow the expected pattern: the hot FID results are about twice the cold bag results. Table II shows the results of some sample point investigations which confirm the approximate 2:1, hot:cold, ratio between the hot FID analysis at the mixing chamber outlet and the bag samples.

The next series of tests, numbers 7 through 12, were run for the Procedures Development Branch and the writer was not involved in the testing. At the end of this six test series the writer integrated the hot FID strip charts and it became apparent that the FID had been malfunctioning during all these tests. The two sets of HC data from runs 7 through 12 in Table I show clearly that something was amiss. The hot FID results should be about twice as high as the cold bag results, but instead are nearly equal to or actually lower than the cold bag results. Investigation of the instrument revealed slow response times and high background HC levels in the instrument. It was theorized that the causes were contamination and deterioration of the instrument over a period of one year of extensive use at the high temperature conditions in extreme environments. The unit was thoroughly cleaned and new parts, including O-rings, gaskets, and filters,were installed.

On the last series of tests, runs 13 through 18, a Scott Model 215 hot FID was used. The deterioration of the instrument's performance during this series is clearly seen in the HC mass data in Table I. Only runs 13 and 14 are considered as valid for HC data. The cause for this gradual decrease in mass emissions data is not known definitely, but a leak in the sample line is suggested. After the diesel testing was completed, breakdowns of this instrument became increasingly frequent and serious, and included sample pump breakdown, clogging of filters, and melting of the sample line due to faulty heater control.

b. Carbon Monoxide

With two exceptions, all the carbon monoxide data listed in Table I were calculated using the concentrations determined by the most sensitive CO analyzer available in the laboratory. At least one of two low range instruments was in use during the Diesel test program. The most sensitive range of each instrument was 0-200 ppm and 0-250 ppm, respectively. The exceptions are runs 11 and 12. Inexplicably on these two runs the low range instruments were not used. Thus, the mass emissions reported (.61 and .96 gpm, respectively) are considered to be very inaccurate and should be disregarded. If these two runs are disregarded the mean CO mass is 1.40 gpm, with a standard deviation of .09 gpm.

c. Nitrogen Oxides

The NOx data in Table I is quite consistent, with one test the exception. On run 9 the measured NOx mass was 2.09 gpm, about 27% higher than the all-test mean of 1.64 gpm. Examination of laboratory records has indicated the probability that this test was erroneously run at an inertia weight of 4,500 pounds instead of the required 3,500 pounds. The higher inertia weight would explain the increased NOx emissions as well as the increased CO_2 emissions on run 9. If, then, run 9 NOx data is excluded from consideration the mean mass is 1.61 gpm, with a standard deviation of .06 gpm, or less than 4% of the mean. It is felt that NOx emissions from this vehicle have been well defined.

d. Carbon Dioxide

Carbon dioxide mass emissions are used to calculate fuel consumption over the Federal test driving schedule, which simulates an urban-suburban commuting trip. CO2 emissions can also be used to determine test validity and CVS performance. To repeat the instance of test number 9, the high CO_2 emissions are an additional indication that the inertia weight was set too high.

Test numbers 1,2, and 3 were run on a different dynamometer from all the remaining tests. The step change in CO_2 emissions, from about 500 gpm to about 400 gpm, is not understood. There is confidence that the inertia weights on the first three tests were correct. It is possible that the CO_2 emissions are the result of engine running-in, since the first three tests were run at odometer readings of 2060 to about 2100 miles and test number 4 was at 2954 miles.

If tests 1,2,3 and 9 are not included, the mean CO_2 mass is 410.82 gpm. The standard deviation is 7.77 gpm, or less than 2% of the mean.

2. Particulate emissions, as determined by the Dow Chemical procedure, are shown in Table III. These values are about 7 times higher than those from vehicles using leaded gasoline, and perhaps 20 times higher than from non-leaded gasoline. The material was pitch black and very fine.

Conclusions

Mass emissions of all three gaseous pollutants from this car were at or below the levels required for the 1975 model year. Average NOx emissions were slightly more than four times the level required for the 1976 model year. The average CO_2 emissions were about 50% of CO_2 emissions from gasoline-powered cars tested at the same inertia weight.

The 1975 FTP with CVS sampling is applicable for all Diesel measurements except HC. No difficulties were encountered in the CVS system as a result of soot build-up.

Hot FID hydrocarbon data is valid from only eight tests: 1 through 6, 13 and 14. It would be desirable to do further testing on a Diesel car to define the HC emissions better and to investigate the effects of lowering FID and sample line temperatures.

TABLE I

Mercedes-Benz 220 Diesel
Gaseous Emissions
(grams per mile)

1975 Federal Test Procedure

Test No.	EPA Test No.	HC Cold Bag	HC Hot FID	CO	NOx	CO_2
1	18-82	.22	.31	1.11	1.61	508.73
2	18-86	.20	.37	1.47	1.49	495.30
3	18-87	.24	.42	1.56	1.50	498.21
4	18-160	.17	.38	1.44	1.47	404.26
5	18-166	.14	.31	1.34	1.62	398.78
6	18-172	.16	.30	1.37	1.62	420.16
7	18-234	.19	.23	1.39	1.62	403.62
8	18-237	.16	.18	1.39	1.61	413.48
9*	18-242	.19	.17	1.38	2.09	463.88
10	18-245	.20	.14	1.44	1.67	427.48
11	18-251	.18	.15	.61**	1.66	413.32
12	18-255	.15	.16	.96**	1.67	407.47
13	18-281	.15	.34	1.51	1.67	421.06
14	18-283	.15	.28	1.40	1.64	416.26
15	18-284	.14	.21B .22S	1.36	1.61	404.73
16	18-287	.14	.17	1.37	1.62	406.94
17	18-291	.14	.12	1.39	1.66	407.48
18	18-292	.14	.16	1.44	1.62	406.42

* 4500 lbs inertia
**High Range (0-2500 ppm)

B = Beckman 402
S = Scott 215

TABLE II

Sample Point Investigations

1. Vehicle at a steady state cruise condition, approximately 30 mph.

   a. Hot FID: 5 ppm (Sample Pt. 2)
      Bag Sample: 2.4 ppm (Sample Pt. 4)

   b. CO_2 at Sample Pt. 2: 19.5 meter deflection
      CO_2 at Sample Pt. 3: 19.5 meter deflection

      Conclusion: There is no leakage of air into the flexible duct between mixing chamber and CVS heat exchanger.

   c. Continuous Hot FID analysis

      HC at Sample Pt. 2: 5 ppm
      HC at Sample Pt. 3: 4.5 ppm

2. Vehicle at a steady state cruise condition.

   a. Continuous Hot FID analysis

      Sample Pt. 1: 17 ppm
      Sample Pt. 2: 2.2 ppm
      Sample Pt. 3: 1.4 ppm
      Sample Pt. 4: 1.2 ppm

Sample Point 1 = Vehicle tail pipe (raw exhaust)
2 = Mixing Chamber Outlet Duct (dilute exhaust)
3 = One foot upstream of CVS Heat Exchanger
4 = Bag Sample Point, just upstream of Rootes pump

TABLE III

Mercedes-Benz 220 Diesel
Particulate Emissions
(grams per mile)

1975 FTP Driving Schedule
Dow Measuring Procedure

Sample Flow Rate	Filter Type	Mass, gpm
4 cfm	Fiberglass	.6642
1 cfm	Fiberglass	.7943
1 cfm	Fiberglass	.7487
1 cfm	Anderson + Millipore	.7313